

## CLAIMS

We claim:

1. A method of facilitating placement of virtual appliances at desired positions on virtual  
10 teeth of an orthodontic patient using a workstation having a processing unit, memory having a  
three-dimensional virtual model of teeth of the patient, and an user interface including a display  
and software executable by said processing unit, comprising the steps of:
  - (a) displaying three-dimensional virtual teeth model of a patient in a user selected  
dentition state of a patient;
  - 15 (b) selecting a virtual appliance placement reference for placing virtual appliances on said  
virtual teeth;
  - (c) placing and displaying a virtual appliance at said appliance placement reference on a  
plurality of said virtual teeth in said user selected dentition state;
  - (d) evaluating said virtual appliance placement for each of said plurality of virtual teeth is  
20 in a desired position; and
  - (e) when one or more of said virtual appliances are not in said desired position, digitally  
simulating alternate placements for said virtual appliances and modifying said placement of said  
virtual appliances in order to achieve the desired placements.
- 25 2. The method of claim 1, wherein said user selected dentition state of said patient  
comprises a malocclusion state.

3. The method of claim 1, wherein said user selected dentition state of said patient comprises a target state.

10 4. The method of claim 1, wherein said appliance placement reference comprises a bracket height reference and wherein step (b) comprises selecting said bracket height reference in at least one of the following ways: (i) for each of said virtual teeth, (ii) for groups of said virtual teeth, (iii) the same for all of said virtual teeth.

15 5. The method of claim 1, wherein said appliance placement reference comprises an occlusal plane reference and wherein step (b) comprises selecting said occlusal plane reference, either in whole or in user selected segments.

20 6. The method of claim 1, wherein said appliance placement reference comprises an arbitrary plane reference and wherein step (b) comprises selecting said arbitrary plane reference, in whole or in user selected segments, in one of the following ways: (i) for lower arch, (ii) for upper arch, (iii) for lower arch and upper arch.

25 7. The method of claim 1, wherein said virtual teeth comprise virtual teeth on (a) lower jaw, or (b) upper jaw, or (c) lower jaw and upper jaw.

- 5     8.     The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof.
9.     The method of claim 1, wherein said verifying step (d) includes examining said virtual  
10     appliance placement (a) locally for each said virtual tooth, (b) for selected groups of said virtual  
teeth, and (c) globally for all said virtual teeth.
10.    The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
15     workstation's memory or a combination thereof and wherein said verifying step (d) includes  
detecting collision (a) between said virtual bracket and said virtual tooth on which said virtual  
bracket is placed on, and (b) between said one virtual bracket and said another virtual bracket.
11.    The method of claim 1, wherein said virtual appliances comprise virtual brackets  
20     prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said modifying said placement of  
said virtual appliances in step (e) further comprises enabling said user in replacing said one or  
more virtual brackets with those from said library of virtual brackets.

- 5     12.     The method of claim 1, further comprising the step of automatically measuring and  
marking said placement of said virtual appliances in relation to the surface of said virtual teeth in  
2D and/or 3D.
13.     The method of claim 1, further comprising the step of enabling said user in measuring  
10     and marking said placement of said virtual appliances using the graph paper display in 2D and/or  
3D.
14.     The method of claim 12, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
15     workstation's memory or a combination thereof and wherein said measuring and identifying the  
placement of said virtual appliances further comprises the step of measuring thickness of the gap  
between said virtual bracket and said virtual tooth surface for placing an adhesive pad.
15.     The method of claim 1, further comprising the steps of displaying said virtual teeth in  
20     said virtual model in the form of a virtual two-dimensional (2D) panorax model with axial  
inclination for each tooth, enabling said practitioner in modifying said placement of said virtual  
appliances, simulating its overall treatment effectiveness on said patient, and when a desired  
placement is achieved wrapping said virtual 2D panorax model in three-dimensional (3D) view.
- 25     16.     The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said

5 workstation's memory or a combination thereof and wherein said verifying step (d) includes  
enabling the practitioner in ascertaining that said virtual bracket is placed on the center of said  
virtual tooth.

17. The method of claim 1, wherein said virtual appliances comprise virtual brackets  
10 prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said verifying step (d) further  
includes enabling the practitioner in viewing said virtual bracket placement using the clipping  
plane and in ascertaining that said virtual bracket is properly adapted to the surface of said virtual  
tooth; and said modifying the placement step (e) further comprises moving said virtual bracket to  
15 realize proper adaptation of said virtual bracket to the surface of said virtual tooth.

18. The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said verifying step (d) further  
20 comprises enabling the practitioner in viewing said virtual bracket placement and in ascertaining  
that said virtual bracket does not penetrate the surface of said virtual tooth; and said modifying  
the placement in step (e) includes moving said virtual bracket to realize proper placement to  
remove any penetration of said virtual bracket from the surface of said virtual tooth.

25 19. The method of claim 1, wherein said appliance placement reference comprises a bracket  
height reference and wherein step (b) comprises selecting said bracket height reference in one of

5 the following ways: (i) for each of said virtual teeth, (ii) for groups of said virtual teeth, (iii) the  
same for all of said virtual teeth and wherein said verifying step (d) further includes enabling the  
practitioner in viewing said virtual bracket placement in relation to the occlusion plane and  
ascertaining that said virtual brackets are placed properly; and said modifying the placement in  
step (e) includes moving said virtual brackets to realize the desired relationship between said  
10 virtual brackets and said occlusal plane.

20. The method of claim 19, wherein said occlusal plane is the upper occlusal plane.

21. The method of claim 19, wherein said occlusal plane is the lower occlusal plane.

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22. The method of claim 19, wherein said occlusal plane is viewed in arbitrary sections  
selected by the practitioner.

23. The method of claim 19, further comprising the step of changing the level of said occlusal  
20 plane and simulating its overall treatment effectiveness on said patient.

24. The method of claim 19, further comprising the step of changing the angle of said  
occlusal plane and simulating its overall treatment effectiveness on said patient.

25 25. The method of claim 19, further comprising the step of changing the curvature of said  
occlusal plane and simulating its overall treatment effectiveness on said patient.

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26. The method of claim 5, wherein said occlusion plane is lower occlusion plane.

27. The method of claim 5, wherein said occlusion plane is upper occlusion plane.

10 28. The method of claim 5, wherein said occlusion plane is lower occlusion plane and upper plane.

29. The method of claim 5, wherein said occlusion plane is derived from cusp tips.

30. The method of claim 5, wherein said occlusion plane is derived from marginal ridges.

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31. The method of claim 5, wherein said occlusion plane is derived arbitrarily.

32. The method of claim 5, wherein said occlusion plane is derived in independent segments.

20 33. The method of claim 1, wherein said virtual appliances comprise virtual brackets prescribed by the practitioner or selected from a library of virtual brackets stored in said workstation's memory or a combination thereof and wherein said verifying step (d) further comprises enabling said practitioner in checking said placement height, angulation, and torque of said virtual bracket and in step (e) simulating the overall treatment effectiveness of said virtual  
25 bracket placement on said patient.

5 34. The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said verifying step (d) includes  
enabling said practitioner in ascertaining that the resulting marginal ridges are lined-up; and said  
modifying said placement step (e) includes moving said virtual bracket or said virtual brackets so  
10 that said marginal ridges are aligned.

35. The method of claim 1, wherein said virtual appliances comprise virtual brackets  
prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said verifying step (d) comprises  
15 enabling said practitioner in ascertaining that the cusp tips are in the desired position; and said  
modifying the placement in step (e) includes the step of moving said virtual bracket or said  
virtual brackets in order to realize the desired positions of said cusp tips.

36. The method of claim 1, wherein said virtual appliances comprise virtual brackets  
20 prescribed by the practitioner or selected from a library of virtual brackets stored in said  
workstation's memory or a combination thereof and wherein said modifying the placement in  
step (e) includes enabling the practitioner in placing said virtual bracket such that the reference  
virtual tooth is blocked from moving and simulating its overall treatment effectiveness on said  
patient.



5 37. The method of claim 1, wherein said displaying said virtual appliances on said virtual teeth further comprises the step of enabling said practitioner in hiding said virtual teeth from the view.

38. The method of claim 1, wherein said simulating in step (e) further comprises the step of  
10 simulating the effectiveness of the archwire configuration in conjunction with said bracket placement and making adjustments when necessary to realize said desired position of said patient's virtual teeth.

39. The method of claim 38, wherein said archwire comprises a straight archwire.

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40. The method of claim 38, wherein said archwire comprises a custom archwire.

41. The method of claim 38, wherein said archwire comprises a hybrid archwire.

5     42.     A method of placing virtual appliances at desired positions on virtual teeth of an  
orthodontic patient for planning mid-course treatment adjustment using a workstation having a  
processing unit, memory having a three-dimensional virtual model of teeth of the patient, and an  
user interface including a display and software executable by said processing unit, comprising the  
steps of:

10           displaying a three-dimensional virtual teeth model of a patient and virtual appliances in  
their current positions in an intermediate treatment state;

selecting a virtual appliance placement reference;

comparing said current virtual appliance placements with the placements recommended

15   by said virtual appliance placement reference;

when said current position of said virtual appliance in said intermediate treatment state  
deviates from said appliance placement reference on said virtual tooth, repositioning and  
displaying said virtual appliance at said appliance placement reference;

verifying that said virtual appliance placement for each said virtual tooth is in desired

20   position; and

when the virtual appliance is not in said desired position, digitally simulating alternate  
placements for said virtual appliances and modifying said placement of said virtual appliances in  
order to achieve the desired placements.

5 43. The method of claim 42, wherein said appliance placement reference comprises bracket height reference selected in at least one of the following ways: (i) for each of said virtual teeth, (ii) for groups of said virtual teeth, (iii) the same for all of said virtual teeth.

44. The method of claim 42, wherein said appliance placement reference comprises an  
10 occlusal plane reference selected either in whole or in user selected segments, in one of the following ways: (i) for lower arch, (ii) for upper arch, (iii) for lower arch and upper arch.

45. The method of claim 42, wherein said appliance placement reference comprises an arbitrary plane reference selected either in whole or in user selected segments, in one of the  
15 following ways: (i) for lower arch, (ii) for upper arch, (iii) for lower arch and upper arch.

46. The method of claim 42, wherein said virtual appliances comprise virtual brackets prescribed by said practitioner or selected from a library of virtual brackets stored in said workstation's memory or a combination thereof.

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47. An apparatus for facilitating placement of virtual appliances at desired positions on virtual teeth of an an orthodontic patient, comprising:

a workstation having a processing unit and a display;

a memory accessible by said workstation storing a virtual three-dimensional model of

25 teeth and/or associated anatomical structures representing the dentition of a patient;

5 software executable by said processing unit to access said model and display said model  
on said display; and

said software further including navigation tools enabling a user to interactively:

- (a) display said three-dimensional virtual teeth model of a patient in a user  
selected dentition state of a patient;
- 10 (b) select a virtual appliance placement reference for placing virtual appliances on  
said virtual teeth;
- (c) place and display a virtual appliance at said appliance placement reference on  
a plurality of each of said virtual teeth in said user selected dentition state;
- (d) verify and evaluate that said virtual appliance placement for each of said  
15 plurality of virtual teeth is in desired position; and
- (e) when one or more of said virtual appliances are not suitably placed, digitally  
simulate alternate placements for said virtual appliances and modify said  
placement of said virtual appliances in order to achieve the desired  
placements.

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48. The apparatus of claim 47, wherein said user selected dentition state of said patient  
comprises malocclusion state.

49. The apparatus of claim 47, wherein said user selected dentition state of said patient  
25 comprises target state.

5 50. The apparatus of claim 47, wherein said appliance placement reference comprises bracket height reference selected in one of the following ways: (i) for each of said virtual teeth, (ii) for groups of said virtual teeth, (iii) the same for all of said virtual teeth.

51. The apparatus of claim 47, wherein said appliance placement reference comprises  
10 arbitrary plane reference selected, either in whole or in user selected segments, in one of the following ways: (i) for lower arch, (ii) for upper arch, (iii) for lower arch and upper arch.

52. The apparatus of claim 51, wherein said arbitrary plane reference comprises occlusal plane reference.

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53. The apparatus of claim 47, wherein said navigation tools further enable the user to view and manipulate marginal ridges.

54. The apparatus of claim 47, wherein said navigation tools further enable the user to view  
20 and manipulate cusp tips.

55. The apparatus of claim 47, wherein said navigation tools further enable the user to view and select reference tooth or teeth.

25 56. The apparatus of claim 47, wherein said appliances are brackets.

5 57. The apparatus of claim 56, wherein said brackets are selected from a library of brackets stored in said workstations' memory.

58. The apparatus of claim 56, wherein said brackets are prescribed by the practitioner.

10 59. The apparatus of claim 47, wherein said appliances are brackets and wherein said navigation tools further enable the user to detect collision (a) between the bracket and the tooth, (b) between the bracket on one tooth and the bracket on the neighboring tooth on the same arch, and (c) between the bracket on one tooth and the bracket on the neighboring tooth on the opposite arch; and to modify the placement by moving the bracket or the brackets to eliminate  
15 collision.

60. The apparatus of claim 47, wherein said appliances are brackets and wherein said navigation tools further enable the user to select a different type of bracket from the bracket library and to replace the current bracket on the particular tooth with the selected bracket and to  
20 simulate its overall treatment effectiveness on the patient.

61. The apparatus of claim 47, wherein the navigation tools further comprise tools enabling the user in automatically measuring and to identifying the placement of the appliances in relation to the tooth surface.

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5 62. The apparatus of claim 47, wherein the navigation tools further comprise tools enabling  
the practitioner in measuring and identifying the placement of the appliances using the graph  
paper display.

63. The apparatus of claim 62, wherein the measurements are enabled in all three dimensions  
10 of space.

64. The apparatus of claim 62, wherein said appliances are brackets and wherein the  
navigation tools further comprise tools enabling the user in measuring thickness of the gap  
between the bracket and the tooth surface for placing adhesive pad.

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65. The apparatus of claim 47, wherein the navigation tools further comprise tools enabling  
the user in displaying the teeth in the virtual model in the form of a two-dimensional (2D)  
panorax showing axial inclination for each tooth, in modifying the placement of appliances,  
simulating its overall treatment effectiveness on the patient, and when a desired placement is  
20 achieved, in wrapping the virtual 2D model in three-dimensional (3D) view.

66. The apparatus of claim 47, wherein said appliances are brackets and wherein the  
navigation tools further comprise tools enabling the user in ascertaining that the bracket is placed  
on the center of the tooth.

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5 67. The apparatus of claim 47 , wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in viewing the bracket placement using the clipping plane and in ascertaining that the bracket is properly adapted to the surface of the tooth; and in moving the bracket to realize proper adaptation of the bracket to the tooth surface.

10 68. The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in viewing the bracket placement and in ascertaining that the bracket does not penetrate the surface of the tooth; and in moving the bracket to realize proper placement to remove any penetration of the bracket from the tooth surface.

15 69. The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in viewing the bracket placement in relation to the occlusion plane and in ascertaining that the brackets are placed properly; and in moving the brackets to realize the desired relationship between the brackets and the occlusal  
20 plane.

70. The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in checking the placement height, angulation, and torque of the bracket and in simulating its overall treatment effectiveness on the  
25 patient.



- 5     71.     The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in ascertaining that the resulting marginal ridges are lined-up; and in moving the bracket or the brackets for aligning the marginal ridges.
- 10    72.     The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in ascertaining that the cusp tips are in the desired position; and in moving the bracket or the brackets for realizing the desired cusp tips positions.
- 15    73.     The apparatus of claim 47, wherein said appliances are brackets and wherein the navigation tools further comprise tools enabling the user in placing the bracket such that the reference tooth is blocked from displacement and in simulating its overall treatment effectiveness on the patient.
- 20    74.     The apparatus of claim 47, wherein the navigation tools further comprise tools enabling the user in displaying bounding boxes around the teeth for aiding in assessing teeth movement.
75.     The apparatus of claim 47, wherein the navigation tools further comprise special visualization tools enabling the user in selecting, visualizing and modifying said patient's axial
- 25    inclinations of crowns and roots of said patient's dentition in 2D and 3D.